ADA213282

R-3604/1-AF

A New View of Weapon System Reliability and Maintainability

Executive Summary

J. R. Gebman, D. W. McIver, H. L. Shulman

January 1989

A Project AIR FORCE report prepared for the United States Air Force

RAND

[illegible] of Rand was sponsored by the United States [illegible] under Contract [illegible]. Further information may be obtained from the Long Range Planning and Doctrine [illegible] Directorate of Plans, Hq USAF.

ISBN: 0-8330-0939-7

Published by The RAND Corporation
[illegible] Santa Monica, CA 90406-2138

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER R-3604/1-AF	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A New View of Weapon System Reliability And Maintainability		5. TYPE OF REPORT & PERIOD COVERED interim
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. R. Gebman, D. W. McIver, H. L. Shulman		8. CONTRACT OR GRANT NUMBER(s) F49620-86-C-0008
9. PERFORMING ORGANIZATION NAME AND ADDRESS The RAND Corporation 1700 Main Street Santa Monica, CA		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Requirements, Programs & Studies Group (AF/RDQM) Ofc DCS/R&D and Acquisition Washington, D. C. 20030		12. REPORT DATE January 1989
		13. NUMBER OF PAGES 18
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

No Restrictions

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Reliability, Maintainability, Weapon Systems, Faults, Avionics, Maintenance, Repair. (JES)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is an executive summary of R-3604/2. (see also R-2908/1, N-2479, N-2549.)

DD FORM 1 JAN 73 1473

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

89 10 3 052

R-3604/1-AF

A New View of Weapon System Reliability and Maintainability

Executive Summary

J. R. Gebman, D. W. McIver, H. L. Shulman

January 1989

A Project AIR FORCE report
prepared for the
United States Air Force

RAND

PREFACE

This summary and the report it summarizes[1] integrate the final results of the project "Methods and Strategies for Improving Weapon System Reliability and Maintainability" conducted within RAND's Project AIR FORCE Resource Management Program. This project, sponsored by the Air Force Special Assistant for Reliability and Maintainability, examined tactical aircraft weapon systems.

BACKGROUND

The Air Force Special Assistant for Reliability and Maintainability and The RAND Corporation jointly developed the research plan that called for RAND to develop methods and strategies for improving weapon system reliability and maintainability (R&M). The sponsor and RAND agreed that the research should concentrate on tactical aircraft weapon systems and answer four questions:

- What kinds of payoffs or benefits can the Air Force expect from improved R&M?
- What kind of information currently contained in the Air Force Maintenance Data Collection (MDC) system is useful in the management of R&M?
- Are warranties an effective way to achieve better R&M?
- Can R&M be improved so that present and future U.S. fighter aircraft can deliver their full designed capability and maintain their margin of superiority in the face of a growing Soviet threat?

Answers to these questions and the supporting research are documented in:

> J. B. Abell, T. F. Kirkwood, R. L. Petruschell, and G. K. Smith, *The Cost and Performance Implications of Reliability Improvements in the F-16A/B Aircraft*, The RAND Corporation, N-2499-AF, March 1988.

> R. L. Petruschell, G. K. Smith, and T. F. Kirkwood, *Using the Air Force Maintenance Data Collection System Data to Identify*

[1]R-3604/2-AF.

Candidates for Improvement in Reliability and Maintainability, The RAND Corporation, N-2549-AF, March 1987.

J. P. Stucker and G. K. Smith, *Warranties for Weapons: Theory and Initial Assessment,* The RAND Corporation, N-2479-AF, April 1987.

J. R. Gebman and H. L. Shulman, with C. L. Batten, *A Strategy for Reforming Avionics Acquisition and Support*, The RAND Corporation, R-2908/2-AF, and *Executive Summary*, R-2908/1-AF, July 1988.

This last effort involved RAND's participation in special data collection and analysis for the F-15 C/D radar and the F-16 A/B radar. It was part of the Air Force's special program on F-15/F-16 Radar R&M Improvement. This special program was an outgrowth of a previous RAND project examining acquisition and support of avionics equipment.

ACKNOWLEDGMENTS

Throughout our efforts, we have received continued assistance from Brigadier General Frank Goodell, the Air Force Special Assistant for Reliability and Maintainability, his staff, other elements of Headquarters United States Air Force, Headquarters Tactical Air Command, Headquarters United States Air Forces Europe, Warner-Robins Air Logistics Center, Ogden Air Logistics Center, the F-15 System Program Office, the F-16 System Program Office, and the Strike Systems Program Office.

In particular we are indebted to Lieutenant Colonel Paul Cunningham, USAF, Captain Glen Titus, USAF, and Phil Stone of Headquarters, TAC, for their advice and support; to Major Louis Medal, USAF; and to Major Paul J. Wolf, USAF. We are also indebted to Lieutenant Colonel James Masters, USAF, AF/LEXY, and T. J. O'Malley, Randall M. King, Lauretta Burke, and Virginia Mattern of the Logistics Management Institute; to Victor J. Presutti, Jr., Captain Mindy Grant, USAF, Michael Niklas, Leonard Kramer, and Donald Keaton of the Air Force Logistics Command; and to our RAND colleagues, Joseph Large, Donald Emerson, Milton Kamins, and Robert Paulson.

The work reported here would not have been possible without the help of several Air Force people who provided us with their valuable knowledge and insights regarding base level maintenance and the Air Force Maintenance Data Collection (MDC) system. We are particularly indebted to Chief Master Sergeant Donnie Hallam and Sergeant George Buchanan of the 338th Tactical Fighter Wing at Hill AFB, and Sergeant Steven Yarosch of the 58th Tactical Training Wing, for helping us learn about the technical side of MDC and about base level maintenance.

During the 1984–1985 special data collection and analysis efforts on the F-15 and F-16 radars, we especially benefited from the assistance of Major Rodney Fisher and Robert Benitez, who were the program managers for the F-15/F-16 Radar Reliability and Maintainability Improvement Program data collection and analysis phase. This phase was administered by the Aeronautical Systems Division Strike Systems Program Office, which received engineering support from Lieutenant Dale Evers and Robert Reed of the Air Force Acquisition Logistics Center, and program technical direction support from Gary Munoz and Gene Swenson of Support Systems Associates, Inc. Charles Spruck led the Hughes Aircraft Radar Systems Group data collection and analysis for the F-15 radar, and Roy Pyle led the Westinghouse Defense and

Electronics Center data collection and analysis for the F-16 radar. William McAllister led the group providing assistance from McDonnell Douglas, the prime contractor for the F-15; James Ross led the group providing assistance from General Dynamics, the prime contractor for the F-16. Participating F-15 units were the 1st Tactical Fighter Wing (TFW) at Langley AFB, Virginia, and the 36th TFW at Bitburg Air Base, FRG; participating F-16 units were the 50th TFW at Hahn Air Base, FRG, and the 388th TFW at Hill AFB, Utah.

RAND's Project AIR FORCE Resource Management Program, which was directed by Michael Rich and then Charles Kelley, provided continuing support, guidance, and encouragement.

Finally, we wish to thank Morton G. Berman and Martin Goldsmith for their thoughtful and thorough reviews.

CONTENTS

EXECUTIVE SUMMARY

Removal of faults that degrade performance of mission essential equipment is the chief R&M challenge facing aircraft weapon systems. To manage an effective response to this challenge the Air Force needs to take a new view of R&M, recognize weaknesses in light of such a view, and adopt an appropriate strategy to strengthen its management of weapon system support, product improvement, and acquisition.

- The view proposed here considers all indications of potential faults. The traditional view relies almost exclusively on the most recent observation or test.
- Weaknesses identified in the processes for supporting, improving, and acquiring weapon systems inadequately view maintainability problems that technicians face in supporting the full measure of specified design performance in modern aircraft weapon systems.
- A strategy for addressing these weaknesses needs to deal with the gathering, analysis, and summarizing of information that reflects a complete view of the R&M situation, including both fault initiation and fault removal.

THE TRADITIONAL VIEW

The traditional view is a carryover from an earlier era when it may have been appropriate to assume:

- If the operators don't complain about it it isn't broken.
- Even if they complain, if the technicians can't duplicate the alleged symptom, it isn't broken.
- If it isn't broken, don't fix it.
- If it was broken, it's fixed as soon as the technicians decide that their actions have corrected the problem.[1]

Although the complexities of mission essential military equipment have long defied such simple assumptions, the processes for acquiring, improving, and supporting complex systems continue to be driven by a

[1]The technician's judgment is questioned only if the operators (flight crews) request maintenance after one of the next three flights. Thus, if flight crews tolerate signs of degraded performance for more than three flights following a maintenance action, the current system implicitly assumes that the maintenance action was fully effective.

set of measures that reinforces such a traditional view of R&M. These measures typically include:

- Fully mission capable (FMC) rate: a measure of availability influenced largely by the pilot's subjective assessment of whether maintenance is needed;
- Mean time between failure (MTBF): a measure of reliability influenced mostly by whether technicians in the air base's shop execute a repair action;
- Mean time to repair (MTTR): a measure of how quickly the technicians on the flight line complete their work.

For highly visible failures, such as total failure of a major subsystem, such measures have been very meaningful. Meaningfulness breaks down, however, as the visible symptoms of failure become more obscure. With the continuing progress in the reliability of Air Force equipment, total failure is becoming increasingly rare. Today, the dominant problem with most equipment is not in totally lost performance, but in degraded performance.

To further complicate matters, the degree of degradation may vary across the different functions that a subsystem performs, with some functions rarely being executed during peacetime training missions. On such missions a pilot may see no symptoms whatsoever for combat-critical faults. Fortunately, modern subsystems have built-in tests (BIT) that can monitor equipment performance and often detect symptoms of such faults. However, because of false alarms and other problems with some BIT systems, especially the early ones that were developed, BIT has developed a spotty reputation that still undermines its credibility with pilots and maintenance technicians. Consequently, if a pilot lacks strong corroborating evidence that a subsystem is broken, he is reluctant to tell maintenance about BIT detected symptoms. There is also a reluctance to share information about pilot perceived symptoms unless there are strong signs that the equipment is broken. Such practices are part of a **pilot tradition** that *you don't ask maintenance technicians to fix something unless you are certain that it is broken.*

Similarly, technicians have been forced to adopt a **maintenance tradition** that *you don't replace an item of equipment unless you are certain that it is broken.* Technicians become certain that an item of equipment is broken only if it fails to pass one of the tests that they apply to it. For example, if the pilot reports that the equipment failed a BIT during a flight, the flight line technicians will run the BIT again on the ground to try and duplicate the BIT detected symptom. If they *can not duplicate* (CND) a symptom on the flight line, or detect any other symptom(s), they usually will not replace any equipment. Likewise, shop technicians at an air base will not replace parts in a unit they are testing if the unit *bench checks serviceable* (BCS); that is, no symptoms of a fault were found. And similarly at a depot, technicians will not replace parts in a unit if it *retests OK* (RETOK) when they run their tests; that is, they found no symptoms of a fault.

Both the pilot and maintenance traditions have been forced by two realities. First, spare parts often are expensive and not always readily available. Second, even under the best of circumstances, the process of replacing an item of equipment may induce damage that is far worse than the disease it is supposed to cure. These realities and traditions create pressures not only to discount but to dismiss information that indicates a fault whenever subsequent observations or tests fail to find symptoms. However:

- Some faults manifest symptoms in only certain environments and under only particular conditions of use.[2]
- During a mission, pilots often are very busy and not always in a good position to evaluate performance degradations in complex equipment.
- Testing is an incomplete and imperfect process, no matter where it occurs.

With modern equipment, these realities have proved to be the dominant causes of the high CND rates, the high BCS rates and the high RETOK rates plaguing current equipments that otherwise have excellent scores in terms of the traditional measures of R&M: FMC, MTBF, and MTTR.[3] While high rates for CND, BCS, and RETOK reflect much fruitless maintenance activity, the more serious concern is the combat preparedness of weapon systems that carry hard to fix faults for prolonged periods of time.

Although maintainability problems of these "bad actors" have been around for a long time, the root causes of such problems have lacked the kind of visibility and emphasis that is being focused on reliability.

---

[2]For example, a loosely soldered wire may manifest symptoms that the pilot can observe only while the aircraft is executing a high g maneuver. Worse, maintenance technicians may have an even rarer opportunity to observe its symptoms because they lack an environmental test chamber.

[3]J. R. Gebman, H. L. Shulman, with C. L. Batten, *A Strategy for Reforming Avionics Acquisition and Support*, The RAND Corporation, R-2908/2-AF, and *Executive Summary*, R-2908/1-AF, July 1988. Unfortunately, faults have been observed lingering in equipment for weeks and even months before finally being isolated and corrected. During 1984, the F-15/F-16 Radar R&M Improvement Program documented this phenomenon with both the APG 63 and the APG 66.

Thus, the view espoused here strives to portray a balanced perspective of both reliability and maintainability.

THE NEW VIEW

For complex military equipment that provides combat essential functions, we believe that the primary objective of R&M needs to be the dependable delivery of the equipment's full measure of designed capabilities.[4]

Currently, the main threat to this objective comes from the type of performance eroding fault that manifests symptoms only in particular situations. Faults with such nonstationary observability are what we term **Type B** faults. This is in contrast to what we call a **Type A** fault, which is one where symptoms are observable no matter when or where the faulty item of equipment is operated or tested. Faults with such stationary observability have the kind of visibility that is needed for the traditional measures of R&M to be meaningful. However, equipments frequently afflicted with Type B faults require a new approach to how we view R&M.

The new approach must deal with both Type A and Type B faults and it must provide full visibility of the two fundamental phenomena that determine R&M:

- **Fault initiation,**
- **Fault removal.**

To do this, we propose a view of R&M based upon a pair of considerations:

- The **frequency with which new faults initiate** within equipment thereby degrading the equipment's ability to dependably deliver the full measure of its designed performance capability.

[4]A contrary view holds that it is unreasonable to expect equipment to continue delivering designed levels of performance long after it has been introduced into service. For example, some systems, such as the solar panels for a spacecraft, are overdesigned initially so that the system will gracefully degrade as the performance of solar elements decline with age. Most aviation electronics equipment, however, is designed based on the assumption that levels of performance must be maintained to cope with growing threats. Accordingly, the whole support process (including BIT and tests at air bases and depots) is based on test requirements that reflect designed capabilities. Deviations from that approach happen mostly when designs fail to achieve specification levels of performance. In such situations, test requirements need to be adjusted. In the event of such derating, though, a fault would be defined relative to the derated level of performance rather than the specified design level.

- The **efficiency with which maintenance technicians remove faults**, thereby restoring the equipment's full measure of specified design performance.

To apply such considerations to an assessment of the R&M situation for a particular subsystem, the Air Force needs a capability to detect degradations in the performance of subsystems. In many instances, however, such a capability is lacking in the environment of routine operations. The Air Force must rely on indications gleaned from *both* pilot observations and BIT detected symptoms. **Although an indication of difficulty from a single flight may not provide satisfactory evidence of a fault, it nonetheless needs to be documented and interpreted in the context of any previous related indications for important patterns to be recognized.**

When a pattern develops, it must be stopped as early as possible even though that may require extraordinary actions by the support process. To minimize the cost and disruptions created by such special actions, repetition of such patterns must be minimized by directing the product improvement process toward rectifying the root causes. Likewise, to minimize the cost of product improvement efforts, the acquisition process should require new equipment and its support process to be designed to minimize susceptibility to repeated patterns of degraded performance.

WEAKNESSES IN MANAGEMENT OF WEAPON SYSTEM R&M

Given this new view of R&M, we next summarize what we learned about the R&M-related weaknesses in the processes for supporting, improving, and acquiring weapon systems and their mission essential subsystems.

Support Process[5]

In several respects, the weapon system support process hinders technicians when they attempt to solve the extraordinarily difficult challenges presented by Type B faults. These difficulties arise mostly in the support of aviation electronics (avionics) equipment. Specifically, the current support process:

[5]See Sec. III of R-3604/2-AF for examples and further discussion.

- Provides too little information about avionics equipment performance during routine training flights,
- Fails to track avionics equipment performance by serial number,
- Inadequately integrates maintenance efforts and fault information across maintenance levels,
- Has inadequate capabilities and procedures for fixing bad actor equipment.

Product Improvement[6]

The product improvement process is important to R&M because it can improve the reliability of the airborne equipment and it can increase the capability of the support process to remove faults efficiently. However, the overall effectiveness of the process as a tool for improving R&M is limited because it

- Functions with inadequate information about dominant R&M problems,
- Fails to accomplish timely implementation of important improvements.

Acquisition Process[7]

The acquisition process represents the first line of defense for R&M. By fielding weapon systems with better R&M characteristics, the need for product improvement can be lessened and the support burden lightened. However, the overall effectiveness of the acquisition process as a tool for improving R&M is limited because it

- Fails to use a meaningful set of management measures for R&M,
- Lacks a process for setting rationally based R&M goals for future equipment,
- Does not provide strong assurances that needed levels of R&M will be delivered.

The Air Force currently uses two basic approaches in its efforts to assure delivery of needed R&M characteristics. In one approach the weapon system's prime contractor is contractually obligated to deliver a product that conforms to the government's specifications. In the

[6]See Sec. IV of R-3604/2-AF.

[7]See Sec. V of R-3604/2-AF.

second approach the government funds any necessary follow-up development and pays to implement needed improvements. Each approach is used in an ad hoc manner that has varied over time and even differs with different subsystems within a weapon system. Neither offers a basis for strong assurances that needed R&M characteristics will be delivered in the future.

The contractual approach is implemented most often in the form of a warranty. Warranties, however, have been implemented in a wide variety of ways depending upon the choices made by the weapon system program office. Some implementations have been viewed favorably because the objective was achieved at what seemed to be a reasonable cost to the government. In other cases the objectives were not achieved or the cost was believed to be too high. Sometimes the perceived costs included a large element due to the time consumed in managing the warranty verification process. Situations where this appeared to be the case were also situations where either the warranty's objectives were unclear or the responsibilities of the contractor and/or the government were unclear.[8]

Because MTBF has been used as a measure in several warranties that have been judged as successfully achieving such an objective, the warranty approach seems well suited to MTBF. Fault removal efficiency, however, is more difficult to measure than MTBF and the delineation of responsibilities is less clear.

One way to try to assure that fault removal efficiency objectives are achieved is for the government to fund whatever follow-up development and implementation proves necessary. A negative aspect of this approach is that the government bears all of the risk for the mistakes made not only by the government's maintenance technicians but also by the many contractors involved: the weapon system prime contractor, the subsystem contractors, the shop test equipment contractor, the depot test equipment contractor, and the contractors who develop the software for the test equipment.

The contractual approach, however, can get hopelessly bogged down in trying to prove who should be blamed: Was it the pilot or one of the government's technicians or was it one of the contractors? If it was a contractor, which one? Furthermore, Type B faults can present especially serious problems in trying to prove blame in specific instances.

[8]J. P. Stucker and G. K. Smith, *Warranties for Weapons: Theory and Initial Assessment*, The RAND Corporation, N-2479-AF, April 1987. The lessons from these experiences are that warranties that have appeared to be successful have been ones that had simply measurable objectives, clear delineation of responsibilities, and reasonable prices.

If the government is going to pay the bill, it should have a standardized approach, rather than having each weapon system pursuing an ad hoc arrangement as is the present case.

STRATEGY FOR STRENGTHENING MANAGEMENT OF WEAPON SYSTEM R&M

To move toward a coordinated strengthening of the Air Force's capabilities to manage weapon system R&M, we propose a cohesive strategy (Fig. 1) that addresses the weaknesses identified in supporting, improving, and acquiring weapon systems. Because strengthening the support process can also produce beneficial effects for both the product

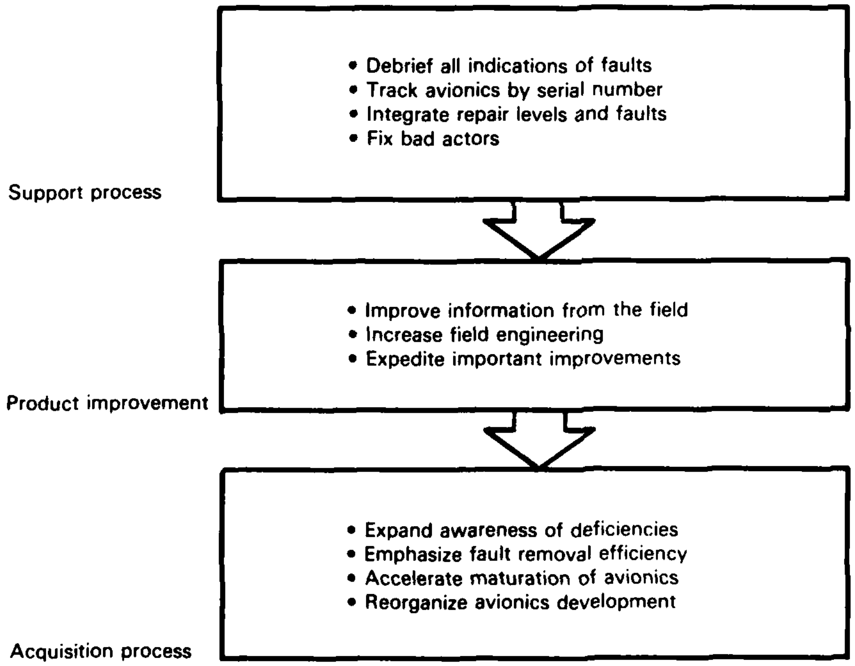

Fig. 1—A cohesive strategy for improving R&M

improvement process and the acquisition process, we start our description of the proposed strategy with the support process.

The Support Process[9]

To strengthen the support process we recommend debriefing pilots for all indications of faults, tracking performance of avionics by equipment serial number, sharing meaningful information about fault symptoms across maintenance levels (flight line to shop to depot), and establishing a special program to repair bad actor equipment.

Debrief Pilots for All Indications of Faults. The first part of the strategy is to debrief pilots to find out what faults they noticed in flight. Pilots need to share with maintenance all the indications of difficulties that they perceive in the operation of complex weapon systems. They do not necessarily have to request maintenance every time they notice an indication, but they need to help maintenance track the performance history of complex subsystems that have a tendency to develop hard to fix faults.

Track Performance of Avionics by Equipment Serial Number. The performance-oriented tracking of complex subsystems that begins with pilot debriefs needs to continue with careful tracking of the subsystem's major components (both LRUs and SRUs), each of which has a unique serial number. Maintenance needs to keep accurate and updated records of which units are being circulated among the aircraft, the shop, and the depot. This step is essential in helping the shop and the depot track and identify the "bad actors" that are in greatest need of special attention to be fixed.

Share Information about Fault Symptoms Across Maintenance Levels. A further necessary element of a strategy for improving the support process calls for sharing meaningful information about fault symptoms across the various levels of the support process. Because the support process must use different tests and different pass/fail criteria at each maintenance level,[10] sharing of meaningful information is especially important to verify that a maintenance action has addressed the same fault that was detected at the previous maintenance level. Such verification is especially needed when trying to rectify Type B faults. To this end, one way to improve information sharing would be to provide **test translation dictionaries** that would enable avionics technicians at one maintenance level to translate test

---

[9] See Sec. III of R-3604/2-AF for additional discussion.

[10] The tests on the aircraft are different from the more detailed tests run in the shop, which in turn are different from the even more detailed tests run on circuit boards at the depot. Unfortunately, these differences serve a necessary purpose.

results from another maintenance level into terms they would find useful for identifying bad actors.

Fix the Bad Actors. The next key element of the strategy is to repair the problem units or components so that they do not circulate between the support process and airplanes in degraded condition. To improve the efficiency of repairing bad actors, we recommend improved fault-isolation capabilities of the various tests by developing:

- Direct entry into test sequences for specific sections of lengthy ground avionics tests at both the base and depot,
- Loop testing for specific tests at both the base and depot,
- Special environmental and system bench capabilities for depots.

Product Improvement[11]

To strengthen the responsiveness of the product improvement process to the root causes of a weapon system's dominant R&M problems we propose a three-part strategy that includes improving the flow of information from the field, increasing field engineering, and expediting important improvements.

Improve Information from the Field. By applying the proposed new view of R&M to data already being acquired by the Air Force's existing maintenance data collection system, the Air Force can better identify areas where further R&M investigation is most needed.[12] Further improvement can come from monitoring and analyzing information from the previously proposed tracking of avionics performance by equipment serial number. By monitoring and analyzing problematic equipment, and the reasons why the routine support process fails to correct their problems, the product improvement process would become more aware of the dominant problems that are undermining the capability of technicians to remove faults efficiently.

Increase Field Engineering. A rational approach to R&M management must include arrangements for addressing the reality that following Initial Operational Capability (IOC) more work will have to be done on any system—especially sophisticated systems such as radars—to raise the maturity of their R&M characteristics to a suitably acceptable level. One way to do this is to get equipment contractor engineers more involved in understanding R&M from the viewpoint of the operators and the maintainers in the field. While a capability to

---

[11]See Sec. IV of R-3604/2-AF for additional discussion.

[12]R. L. Petruschell, G. K. Smith, and T. F. Kirkwood, *Using the Air Force Maintenance Data Collection System Data to Identify Candidates for Improvement in Reliability and Maintainability*, The RAND Corporation, N-2549-AF, March 1987.

do performance-oriented tracking of equipment (especially after attempted repairs) will help, an actual presence in the field will be required to identify the root causes of dominant problems in the more complex subsystems. This will require more special data collection activities such as the one that examined the F-15 and F-16 radars during 1984.[13]

Expedite Important Improvements. A more timely implementation of the most critically needed improvements can be achieved through earlier identification of needs and opportunities and accelerated implementation of selected improvements. Earlier identification would occur if acquisition programs routinely included more detailed data collection efforts by the contractors of the more complex subsystems. Such efforts normally should commence shortly after the IOC date. Accelerated implementation could occur if the Air Force developed special procedures to expedite management and to preprovision funds that would be applied as critical improvements were defined.[14]

The Acquisition Process[15]

To strengthen the role of the acquisition process in managing weapon system R&M, we recommend expanding awareness of R&M deficiencies, emphasizing fault removal efficiency, accelerating maturation of avionics, and reorganizing avionics development.

Expand Awareness of R&M Deficiencies. To improve the R&M record of the acquisition process, the government and industry organizations that are responsible for the development of new equipment need to expand their awareness of the dominant R&M deficiencies in currently fielded equipment. Implementation of the proposals to strengthen the support process and the product improvement process will highlight such deficiencies and their root causes. Thus, efforts to improve the acquisition process will benefit from improvements to these other processes. An improved acquisition process will in turn lighten the burdens that now must be borne by these other processes.

---

[13] See Gebman, Shulman, and Batten, 1988 and R-3604/2.

[14] Implementation of improvements for the F-15/F-16 Radar R&M Improvement Program are proceeding routinely. Adoption of special procedures may considerably shorten the time required to implement the most critically needed improvements. In addition to preprovisioning of funds, there also is a need for advanced preparation of contracts between the Air Logistics Centers and the weapon system's contractors before program management responsibility transfer (PMRT) from the Air Force Systems Command to the Logistics Command. The prolonged lack of a signed contract following PMRT seems to have delayed work on some F-16 radar improvements.

[15] See Sec. V of R-3604/2-AF for additional discussion.

Emphasize Fault Removal Efficiency. Improved awareness of the dominant problems is only an initial step that needs to be followed by a greater emphasis on fault removal efficiency in new developments. We propose that the Air Force adopt fault removal efficiency in conjunction with the MTBF parameter to provide a comprehensive capability to view the overall R&M situation for complex subsystems in aircraft weapon systems.

An example can show the utility of an indicator such as fault removal efficiency. Suppose a subsystem averages 82 flight hours between flights with a failure confirmed by the shop (MTBF = 82 hours) and averages 6 flight hours between flights with an indication of one or more faults. While the MTBF indicates very good reliability for a technologically sophisticated subsystem in a modern combat aircraft, the comparatively lower MTBI (mean time between indication) raises a flag about the subsystem's maintainability, as does the following estimate for the fault removal efficiency:[16]

$$\begin{array}{c}\text{Fault}\\ \text{Removal}\\ \text{Efficiency}\end{array} = \frac{6 \text{ hours}}{82 \text{ hours}} \times 100\% = 7\%$$

This result means that maintenance personnel could find a shop-confirmed fault in this subsystem for only 7 percent of the flights where symptoms were indicated for one or more faults. This maintainability indicator insures that a high reliability indicator does not obscure a subsystem's poor maintainability.

Such a low fault removal efficiency should draw acquisition management attention to the possibility of problems in one or more of the following areas: the timeliness of requests for maintenance, the avionics subsystem itself, the BIT, the shop equipment and tests, the depot equipment and tests, the Technical Orders, and training of maintenance personnel.

Accelerate Maturation of Avionics. This element of the strategy for strengthening the acquisition process aims at more timely and fuller achievement of R&M goals. Although it focuses on aviation electronics (avionics),[17] because this class of equipment currently presents the greatest R&M challenges, the concept of maturation applies to the development of very complex systems.

Our general concept is based on viewing the research and development of a very complex weapon system as a process that has six basic phases:

---

[16]See Gebman, Shulman, and Batten, 1988 for further details.

[17]Including airborne electronic warfare equipment.

I. Technology development
II. Critical component development
III. Subassembly development
IV. Assembly/unit development
V. Subsystem development
VI. Weapon system integration development.[18]

An orderly and efficient development program will invest just the right amount of time and resources in each phase; and although phases will overlap, they will be neither initiated nor terminated too early.

During each basic phase, we use the concept of maturity as a qualitative gauge of the status of development efforts. We say that a phase has reached **maturity** when both the *state of knowledge* and the *level of performance (including R&M characteristics)* are such that it is reasonable to initiate the next phase. The term **full maturity** designates the situation where knowledge and performance have so advanced that it is reasonable to terminate the development work within that phase.

Our general concept of maturation holds that when one is deciding whether to initiate or to terminate a phase, the decision should be based on scientifically accumulated evidence of progress and an objective assessment of the likelihood that lingering difficulties can be resolved before the next phase gets too far along. Within this framework, we can examine the soundness of the basis for decisions in terms of how much the phases preceding a decision have systematically explored possibilities and alternatives using the scientific method.

Throughout the development process, there is pressure to initiate the next basic phase of development sooner rather than later. Even when done too soon, development programs often survive, although R&M characteristics may suffer. Over the years, RAND's research on avionics R&M has seen such pressure take a large toll on R&M during Phase V (subsystem development) and Phase VI (weapon system integration development). Because of this, much of RAND's recent avionics research has focused on strengthening the acquisition process during Phases V and VI.[19]

For these phases, we have proposed a particular form of the general concept of maturation that we call *maturational development*. Because the development of avionics subsystems and associated support

---

[18]We define the weapon system to include the system-peculiar ground support equipment in addition to whatever other data and equipment are required to fully restore the capabilities of the airborne equipment. Such equipment goes through the noted development phases just as does the airborne equipment. Phase VI is then responsible for integrating all of these elements.

equipment often proceeds at a fast pace, little of the systematic maturation advocated by the general concept takes place. To correct this situation, the Air Force should institute a formal period in the acquisition process for which development programs would be required to set aside time and resources for:

- Measuring operational experience, organizing and recording R&M-related data, interpreting the data, and drawing conclusions about the root causes of the dominant problems that are responsible for any shortfalls in needed R&M characteristics.
- Correcting R&M deficiencies, preferably before transfer of PMRT to the Air Force Logistics Command.

We recommend a formal maturational development phase for three classes of complex combat-essential avionics subsystems:

- New subsystems that are just beginning development,
- Already fielded subsystems[20] that are being modified to improve their functional performance,
- Already fielded subsystems where improvements in R&M would considerably narrow the gap between specified design performance and operationally available performance.

Often, the cost to retrofit R&M improvements can be quite high. In those cases, maturational development offers the largest benefit-to-cost ratio when aimed at new avionics subsystems that are just beginning development (Phase V of the development of a weapon system). Maturational development should occur *prior to high-rate production* to avoid the high costs of retrofitting hardware. For this class of equipment, the Air Force might most profitably begin with new avionics for its next generation of tactical fighters.[21]

Reorganize Avionics Development. This final element of the strategy for strengthening the acquisition process aims at reducing the R&M-related development problems that occur throughout the process

[20]Even if a subsystem does not experience a maturational development phase as part of its development, such a phase later in the subsystem's life cycle may still be worthwhile, especially if it is synchronized with a major upgrade that requires hardware modifications. Sometimes, the marginal cost of adding an R&M improvement can be quite modest if it is done at the same time that the equipment is being modified to receive a performance improvement. Such an R&M improvement might otherwise be unaffordable.

[21]One alternative that provides the time to incorporate a maturational development phase is to defer the onset of high rate production. If that is unacceptable, another alternative is to start full-scale engineering development early enough to provide time for maturational development. Currently, the Air Force's System Program Office for the Advanced Tactical Fighter is leaning toward the former.

of developing a weapon system. To this end, we propose a reorganization of avionics development responsibilities that has two purposes:

- Expedite the maturation and application of new technologies by better focusing both government and industry sponsored R&D during Phase II (critical component development), Phase III (subassembly development), and Phase IV (assembly/unit development).[22]
- Institutionalize maturational development during Phase V (subsystem development) and Phase VI (weapon system integration development).

Ideally, subsystem development (Phase V) would start far enough ahead of weapon system integration development (Phase VI) to allow a maturational development effort to be underway before Phase VI begins. Although such a Phase V application of maturational development would have to see the subsystem hosted on a different weapon system for the gathering of operational experience,[23] the advantage of such long lead development of critical subsystems is that design improvements can be incorporated before the start of high rate production for the new host weapon system.

The development of subassemblies (Phase III), such as common modules for integrated communication, navigation, and Identify Friend or Foe (IFF) equipment, provides a further source of need to reorganize the approach to avionics development. Current interest in the development of common avionics modules is fueled by the desire to:

- Lessen the need for air base avionics shops,
- Reduce the amount of new avionics equipment that must be developed for each new weapon system.

This technology will allow a group of common modules to be used both *within* a subsystem and *across* several subsystems.[24]

---

[22]See Gebman, Shulman, and Batten, 1988 for details.

[23]Although this is an incomplete environment for identifying subsystem integration problems, it does provide an operational opportunity to exercise the subsystem in an airborne environment that is a close approximation to the intended operational setting. Moreover, for efficient integration of complex subsystems, it is beneficial to iron out most of the subsystem problems before integration.

[24]Efforts to develop common modules also aim at developing smaller and cheaper LRUs, which in turn would reduce the need for an AIS. Current LRUs are so costly, removed so often, and in such short supply that each air base generally needs its own avionics shop. Because many LRUs cost between $100,000 and $500,000, the avionics shop uses large sets of test equipment to identify faulty SRUs within these LRUs. The shops then send these less expensive SRUs to the depot for repair. This practice reduces the time valuable assets are tied up in the repair pipeline.

The avionics industry and various Air Force organizations are examining the concept of more modular avionics.[25] Rather than building a radar with less than nine LRUs, these efforts aim at building a radar with 50 to 100 modules or perhaps more. Like LRUs, these modules could be removed at the flight line; like SRUs, they would be less expensive and could be sent to the depot for repair.

Although the adoption of common modules has many attractive features, it also presents some R&M-related challenges for the acquisition process. These include

- Establishing a modular avionics architecture that has sufficient flexibility to support high levels of maintainability,
- Orchestrating adequate time and resources to mature the basic R&M characteristics to provide low rates for new faults and high efficiencies for fault removal.

To improve the government's ability to carry out a greater role in funding and directing the evolution of combat critical avionics equipment, we propose a single Air Force organization with development responsibilities for supporting multiple weapon systems.[26]

Such reorganization, and the attendant increased role for the government in avionics development, will initially increase the cost of acquiring avionics equipment. Depending upon how widely common modules are applied across different subsystems, and upon the extent to which R&M characteristics are improved, total lifecycle costs may be lessened by such a new approach. Improved R&M will improve the readiness of equipment to deliver its full measure of specified design capabilities. For the combat essential capabilities of critical equipment, that is the important bottom line.

RECOMMENDATIONS AND CONCLUSION[27]

Although the traditional view of R&M may deal adequately with problems that are consistent show stoppers, a new view is needed to deal effectively with faults that only degrade performance and/or manifest situation-dependent symptoms. Because many of the R&M problems with modern avionics are of the latter category, we have proposed

[25]These efforts include an Air Force Avionics Laboratory program known as PAVE PILLAR, an Air Force Air Staff effort known as Modular Avionics System Architecture, and various industry efforts known as Line Replaceable Modules.

[26]See Gebman, Shulman, and Batten, 1988 for details.

[27]We repeat here, verbatim, the complete recommendations and conclusions found in Sec. VI of R-3604/2-AF.

an approach to viewing R&M that emphasizes the two most fundamental R&M characteristics:

- Fault initiation and
- Fault removal.

Managers need a minimum set of indicators that provide a comprehensive characterization of how a system or subsystem is doing in terms of these fundamental characteristics. We have suggested two:

- Mean flight time between flights with shop confirmed failures,
- Fault removal efficiency.

Using such parameters to analyze contemporary field experience, we find progress in MTBF but considerably less in fault removal efficiency. To address low fault removal efficiency with contemporary equipment, we have proposed several actions aimed at bolstering the capability of the support process. Such improvement alone will not be sufficient. Product improvement actions must examine the dominant causes of low fault removal efficiency, and important improvements must be expedited to bolster the supportability of specific equipment. The high expense of such product improvement makes it far more desirable for future acquisition programs to build in high fault removal efficiency.

Because of the low rate of turnover in military equipment, strengthening the acquisition process alone is not sufficient in the near term. Even with the best of improvements in acquisition programs, it will still be important to bolster product improvement programs and strengthen the support process to cope with problems currently in the field. For these reasons, we have developed a strategy for strengthening the Air Force's capability to manage weapon system R&M during *all* phases of the weapon system life cycle.

Perhaps most obvious in the strategy summarized in Fig. 1 is that at each stage—support, product improvement, and acquisition—there is a critical need for better information from the field. Maintenance personnel need this information to deal quickly and effectively with faulty assets that escape repair, especially with the less than fully mature equipment already in the field today.

To improve the isolation and correction of faults that degrade performance, the Air Force must enhance the quality of information received from the pilot debrief and improve the tracking and correction of R&M deficiencies. When equipment that has resisted repair efforts is located, the support process needs greater capabilities to fix hard problems so that faulty equipment does not circulate between shops and aircraft in degraded condition merely because no one knows how to fix it.

For enhancing the product improvement effort, we recommend improvements in systems for gathering information and engineering data about field problems, an increase in the amount of field engineering analysis, and expediting of important improvements in products.

For improving the acquisition process we recommend expansion of awareness of deficiencies in the process, adoption of the maintainability indicator of fault removal efficiency, maturational development, and reorganization of avionics development to better address current problems and meet future challenges.